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A MODEL OF A MEMORY MECHANISM

by

R. Granovskaya, I. Bereznaya

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A MODEL OF A MEMORY MECHANISM

By: R. Granovskaya, I. Bereznaya

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В в	*В в*	V, v	Т т	*Т т*	T, t
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Д д	*Д д*	D, d	Ф ф	*Ф ф*	F, f
Е е	*Е е*	Ye, ye; E, e*	Х х	*Х х*	Kh, kh
Ж ж	*Ж ж*	Zh, zh	Ц ц	*Ц ц*	Ts, ts
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К к	*К к*	K, k	Ъ ъ	*Ъ ъ*	"
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М м	*М м*	M, m	Ь ь	*Ь ь*	'
Н н	*Н н*	N, n	Э э	*Э э*	E, e
О о	*О о*	O, o	Ю ю	*Ю ю*	Yu, yu
П п	*П п*	P, p	Я я	*Я я*	Ya, ya

*ye initially, after vowels, and after ъ, ь; e elsewhere. When written as ё in Russian, transliterate as yё or ё. The use of diacritical marks is preferred, but such marks may be omitted when expediency dictates.

GREEK ALPHABET

Alpha	Α	α	∝	Nu	Ν	ν	
Beta	Β	β		Xi	Ξ	ξ	
Gamma	Γ	γ		Omicron	Ο	ο	
Delta	Δ	δ		Pi	Π	π	
Epsilon	Ε	ε	ϵ	Rho	Ρ	ρ	ϱ
Zeta	Ζ	ζ		Sigma	Σ	σ	ς
Eta	Η	η		Tau	Τ	τ	
Theta	Θ	θ	ϑ	Upsilon	Τ	υ	
Iota	Ι	ι		Phi	Φ	φ	ϕ
Kappa	Κ	ϰ	κ	Chi	Χ	χ	
Lambda	Λ	λ		Psi	Ψ	ψ	
Mu	Μ	μ		Omega	Ω	ω	

RUSSIAN AND ENGLISH TRIGONOMETRIC FUNCTIONS

Russian	English
sin	sin
cos	cos
tg	tan
ctg	cot
sec	sec
cosec	csc
sh	sinh
ch	cosh
th	tanh
cth	coth
sch	sech
csch	csch
arc sin	$\sin^{-1}$
arc cos	$\cos^{-1}$
arc tg	$\tan^{-1}$
arc ctg	$\cot^{-1}$
arc sec	$\sec^{-1}$
arc cosec	$\csc^{-1}$
arc sh	$\sinh^{-1}$
arc ch	$\cosh^{-1}$
arc th	$\tanh^{-1}$
arc cth	$\coth^{-1}$
arc sch	sech^{-1}
arc csch	csch^{-1}

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rot	curl
lg	log

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A MODEL OF A MEMORY MECHANISM

R. Granovskaya, I. Bereznaya

For the structural input and output of the model, we use a most simple uniform linear circuit made of logical neuron-like elements which are joined with one anotehr sequentially and, by a method of processing the input information, can be compared with on-off-neurons [1].

Besides the on-off-neurons, the structure of the entire model includes a number of other elements, the mathematical models of which are obtained from some primary model by superimposing restrictions specific for each type of elements on it.

As the initial, we took a model of an adding neuron of a threshold element which was detected by physiologists at all levels of the CNS (central nervous system). This neuron possesses a memory at each input in the form of synaptic weight. Models of all other elements used in the memory model are constructed on the basis of the hypothesis that all specific neurons in the CNS are derivatives of the adding neuron and are formed by limitations which are connected with the position of the neurons in the CNS and with the specific nature of the external signals [2].

The model of the on-off-neuron reacts to the threshold differential of signals in time at the inputs. It is compared with the neurons which were first detected in the visual system of frongs, and subsequently, in the hearing, sensory, and other parts of the CNS.

A model of the "neuron of innovation" reacts to the threshold differential of signals in its inputs, and the neuron of identity - to the constancy of signals in its inputs or in time (the neuron of identity in space or time).

The model of the "pH neuron" reacts in the case where there is a simultaneous threshold differntial of signals in the space of its inputs and in time; with a sufficiently low threshold it will react only to the threshold in time, and with an increase in threshold - only to the aggregate of these conditions.

The models of "neurons of identity" in time and space react only when either all of their inputs are in identical states or one input maintains its state invariable in time. This is equivalent to the mathematical concept of identical functions. In this work these neurons are called neurons of innovation, where by innovation there is meant the presence of differentials in the space of the neuron's inputs.

Conditions for triggering various types of neurons have the following form:

Adding neuron (Σ):

$$p(t+1)=1\left[\sum_{i=1}^{k}\sum_{\tau=t-\Delta t}^{t} S_i(\tau)e_i(\tau)-m(t)\right].$$

A difference neuron of the on-off type

$$p(t+1)=1\left[\sum_{i=1}^{k}\sum_{\tau=t-\Delta t}^{t} S_i(\tau)|\Delta e_i(\tau)|-m(t)\right].$$

A "neuron of innovation"

$$p(t+1) = 1\left[\sum_{1<i<j<k} |e_i(t) - e_j(t)| - m(t)\right].$$

A "neuron of identity in space"

$$p(t+1) = 1\,[S_r e_r - m(t)].$$

$$m(t) = m(0) + \sum |S_i e_i(t) - S_j e_j(t)|.$$

A "neuron of identity in time"

$$p(t+1) = \Theta\,[S_r \cdot e_r - m(t)], \qquad S_r e_r > m(0),$$

$$m(t) = m(0) + \sum_{\tau=t-\Delta t}^{t} \cdot S_i\,[e_i \cdot (\tau) - e_i(\tau-1)],$$

$$1(x) = \begin{cases} 1, x \geqslant 0 \\ 0, x < 0 \end{cases} \qquad \Theta(x) = \begin{cases} 1, x > 0 \\ 0, x < 0 \end{cases}$$

Pt - the state of the output at moment t;
li(t) - state of the i-th input;
m(t) - threshold m(o), threshold with t = 0;
τ - internal delay
l_r - state of the input from the generating cell;
k - number of inputs;
S_i - synaptic coefficient of the i-th input;
S_r - synaptic coefficient of the input from the generating cell.

The logical function realized by the adding neurons is determined by their thresholds. The on-off and "innovation" neurons realize the logical function of addition modulo 2, and the "neurons of identity" realize the logical functions of equivalence.

A time-ordered binary M-bit code combination, called the M-code arrives sequentially, bit by bit, at the input of the basic circuit as the information on the objects.

To begin with, we will examine a model of the structure which consists only of the basic circuit, the elements of which (the on-off neurons) do not possess memory. In this structure information on the objects can only be stored in dynamic form.

The specific nature of the transformation of the binary M-code by an on-off type neuron lies in the fact that the reciprocal substitution of zero and one in the input code does not change the process of transformation in the basic circuit.

An analysis of the process of transformation of the M-codes by the basic circuit showed that cases where the input code has length $M = 2^n$ bits it has specific peculiarities (length of the examined basic circuit was limited to 20 neurons). Passing sequentially through the neurons of the basic circuit, this code first is converted to a periodic M/2-bit code, then after the next several elements - to an M/4-bit code, etc., then to an $M/2^{n-v}$-bit code, and then, after two neurons, it becomes a zero code.

In the case of the transformation of the code of bit configuration $M \neq 2^n$, we can discriminate from the basic circuit a group of series connected neurons in which there develops a periodic process of transformation of the codes of the neurons with a period Θ; here the code does not exist as zero at the output of any single element of the basic circuit. The value of Θ depends on M and not on the type of code.

The transformation of codes in the basic circuit can be compared with an autonomous finite automaton which, as is known, can either achieve equilibrium for a finite number of cycles or periodically repeat the finite sequence of states. The M-code can be compared with the information acquired with the bypassing of some object's loop if the loop is closed and divided into M intervals, and each interval is compared with zero or with one.

If the object's loop is divided into $M = 2^n$ intervals and if the result of the bypass of the object over the loop is fed to the input of the basic circuit from the on-off neurons, then a zero code will be at the output of the M-th neuron of the circuit.

The described stages of transformation of the M-code can be compared with the individual stages of analysis of the loop of the object. For storage and analysis of the objects with a quantity of intervals equal to 2^n, there is no sense in circuits being longer than the 2^n neurons. If it is necessary to erase some input code from the memory, then it is sufficient to supplement it arbitrarily up to an overall digit in the period up to 2^n.

If the object has $M \neq 2^n$ intervals and if the result of bypassing the object over to the loop is passed through the circuit from the on-off neurons then the periodic process of transformation along the length of the circuit takes place. The period can be less than, equal to, or greater than M depending on the number of M.

The result of the bypassing of the object over the loop of the M-code has an internal subperiod, i.e., the object has repetitive properties on the aggregate of a number of adjacent intervals, and if the number of digits in one subperiod is $m = 2^n$, then this code is converted to a zero code already at the output of the m-th neuron of the circuit. In other words, for its analysis we can us a circuit which is shorter than that which would be required for an analysis of an object without internal periodicity of properties. The investigation of the transformation of the input codes by elements of the basic circuit showed that we can restore the input information without its conversion to static storage [3, 4]. In this case, the number of digits of the restored input code is limited by the length of the basic circuit. The restoration mechanism in this case is such that from the

information on the state of all the elements of the basic circuit at the recorded moment of time we can restore the state of the circuit at all the preceding moments in time, and also the input code - according to certain recurrent logical relationships. It has been shown that the algorithm for restoration of the input code can be realized in this manner, for example, with the aid of a network of models of both innovation and adding neurons.

As an element of the structure of a static memory we introduced variable synaptic weights of each neuron which reflected the state of a neuron of the basic circuit with the arrival of an M-code at its input. The synaptic coefficient of the input of a neuron changes by a fixed value depending on the code situation at the input of this neuron. By the code situation at the input we mean a pair of binary symbols which corresponds to the values of the adjacent bits of the M-code at the adjacent moments of time. We used a system of three synaptic coefficients which correspond to the storage of: 1) the input situation 00 - the increase of the synaptic coefficient in this case is indicated by α, 2) the input situation 01 or 10 - β, 3) input situation 11 - γ. Each of these three synaptic coefficients of the neuron is greater than zero by as many whole units as the number of times that at adjacent moments of time situations 00, 01, or 10 and 11 were encountered at the input of the neuron.

For a transfer of information about the input code to static storage, elements are necessary which react only to situations α, β and γ. We used as such elements models of neurons of identity in time T_B and on-off as these elements, the set of which, together with the adding neurons, is also the static memory of each element of the basic circuit.

Thus, the time-ordered binary code sequence at the input of the circuit of the on-off neurons and each neuron separately changes with the ordering of values of synaptic weights in the space of the memory circuit.

in connection with the property of the used model of the on-off neuron to react identically to switching on and off, some M-codes for it will be equivalent, i.e., passing through such a neuron, they will leave identical traces in its memory - the coefficients α, β, and γ will acquire identical increases. Specifically, codes of one class of equivalence are equivalent for the on-off neuron. The number of classes of equivalence for various M is determined:

$$\eta(M) = \frac{1}{M} \sum (2^{d} - 2)\, \nu(d, M),$$

where

$$\nu(d, M) = \begin{cases} 0, & \text{если}^{(1)}\ d = 1 \\ 1, & \text{если}^{(1)}\ d = M \\ -1, & \text{если}^{(1)}\ d \neq M, 1 \end{cases}$$

(1) if

with α the internal subperiod in the input code.

It has been shown that according to values α, β, and γ of one neuron of the basic circuit we can restore the code which passed through it with some accuracy [5]. In a number of special cases this accuracy is determined by one class of equivalence. In these cases we can, with an accuracy up to the equivalence class, restore the input M-code for the entire basic circuit if, besides α, β, and γ of one i-th neuron, one of the two symbols α and γ of the preceding neurons is determined.

In the proposed model of memory, the length of the restored input code does not depend on the length of the basic circuit, but is limited only by the range of changes of α, β, and γ.

The model of static memory includes the basic circuit of on-off neurons with a variable threshold (which permits separating the processes of instruction and reading). Connected with each of the elements of the basic circuit is a network of its static memory which in turn consists of neurons which discriminate situations α, β, and γ, and adding neurons (counters) with a

variable threshold, and also its restoration circuit. This network is connected with counters and permits comparing their contents with the corresponding parameters of the examination input code.

The proposed model of static memory operates in an identification mode: if in the reading mode at the input of the model there arrives an examination code which has a similarity for the assigned number of symbols to the code which passed through the basic circuit in the recording mode, then a signal of coincidence appears at the output of the model.

The process of restoration is described in the form of a recurrent algorithm. In each part of this algorithm the presented code is compared with the information in the counters of one neuron of the basic circuit; in the case of detection of a coincidence with regrd to symbols α, β, and γ the code is transformed according to a specific rule to another code which then is analyzed at the next step.

The similarity of the examination code to the stored code is manifested within the limits of the memory of one neuron up to the memory of all on-off neurons of the basic circuit, i.e., the greater the part of the algorithm accomplished by the given examination code, the greater its similarity to the code stored in the memory. Thus, the described network also provides the possibility of introducing a quantitative estimate of the similarity from the degree of utilization of the algorithm by the examination code.

A special feature of the described network is the fact that information on the object is not connected with the specific nature of a concrete problem of classification, and therefore the stored information on the object can also be used for solving problems of classification according to any criteria, and for identifying objects.

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